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2. Patent application number *(The Patent Office will fill in this part)* 12 DEC 2003 **0328904.8**

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04439758001
Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

Scarab

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Kilburn & Strode
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Patents ADP number *(if you know it)* 125001

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Optical measuring system

The present invention relates to a method of measuring amplitude and phase variations within a beam of light, to a method of characterising a beam of light to apparatus for measuring amplitude and phase variations in a beam of light, and to apparatus for characterising a beam of light.

In many optical systems throughput efficiency, crosstalk and noise level depend on the alignment of the various components with respect to one another and to the optical beams passing through. An important problem during assembly of many free space optical systems is that the beam is not visible and its properties cannot be measured as it is incident on the various components in the system, except where the component happens to be a detector array. Even with a detector array measurements are restricted to the intensity when it is the phase distribution that would be more usefully measured.

Usually measurements are confined to overall coupling efficiency into the intended output or some intermediate output.

The more components there are to adjust the more variables there are to optimise, and working "blind" the whole procedure can be very time consuming and expensive. A further problem is that the beams in a real optical system, although maybe Gaussian-like in theory, often have sidelobes due to aberrations, especially when lenses are misaligned. A search for a global optimum can lead to an apparent optimum alignment that instead results in a sidelobe being coupled into the output, rather than the main peak. The existence of such subsidiary maxima makes it more difficult to optimise the alignment.

Often the components themselves are not ideal. For example lenses have a tolerance in dimensions and focal length that makes pick and place assembly inappropriate, while angle-polished fibres have a tolerance in the polish angle. As a result the relative longitudinal spacing, transverse offset and tilt of an optical fibre and lens may need to be adjusted to suit the properties of that lens and fibre. The relative orientation of the lens-fibre assembly may need to be adapted to the rest of the system.

Liquid Crystal over Silicon spatial light modulators (LCOS SLM) are pixellated devices which may be used for applying phase modulation to incident light beams. LCOS SLMs may be used to carry out many optical processing functions such as correlation, monitoring a beam by tapping off a small fraction of the incident energy, routing a beam, changing a beam focus, aberration correction, changing a beam shape or changing the power carried by a beam.

Embodiments of the invention are aimed at providing an ability to assist with the alignment problems mentioned above by enabling a more complete characterisation of beams in an optical system. The invention is however not restricted to this area.

According to one aspect of the invention there is provided a method of measuring amplitude and phase variations in a beam of light comprising causing the beam to be incident upon a spatial array displaying a pixellated first phase distribution, in a measuring region of said spatial array causing the phase distribution to assume a new value while retaining the first phase distribution outside the measuring region, in the Fourier plane determining the change in intensity resulting from the change in phase distribution.

According to another aspect of the invention there is provided a method of characterising a beam of light, comprising disposing a LCOS SLM in the path of the beam; causing the LCOS SLM to display a first hologram pattern; at a location in said beam where the amplitude and phase of the beam are to be characterised, changing the hologram pattern to a second hologram pattern; and measuring the effect of said change by measuring an intensity

In an embodiment, the output from the SLM is measured in the Fourier plane to detect the Fourier output.

In an embodiment, the method comprises measuring the intensity in a region of the Fourier plane where $F_0(x,y)$ is very weak but $g(x,y)$ is relatively stronger, varying the position on the SLM where the perturbation is applied to form a set of measurements of $(g(x,y)f(u_0,v_0))^2$ taking the square root of these measurements to derive values for the relative field amplitude at these positions.

In an embodiment, the method comprises stepping through a sequence of phase distributions.

In an embodiment, the method comprises varying the phase shift in a respective single pixel.

According to another aspect of the invention there is provided apparatus for measuring amplitude and phase variations in a beam of light, the apparatus comprising a pixellated spatial array, each pixel being controllable to apply any of plural phase shifts to input light, whereby the array displays a desired distribution of phase modulation, means for causing the array to display a first selected distribution of phase modulation; means for changing the first

distribution in a measuring region of said spatial array to assume a new distribution while retaining the first phase distribution outside the measuring region; means disposed in the Fourier plane for determining a change in intensity of light resulting from the change in phase distribution.

According to a further aspect of the invention there is provided apparatus for characterising a beam of light, comprising a LCOS SLM arranged so that a said beam of light can be incident upon it; means for causing the LCOS SLM to display a first hologram pattern; means for changing the hologram pattern to a second hologram pattern at a location in said beam where the amplitude and phase of the beam are to be characterised; and means for measuring an intensity of light to determine the effect of said change of hologram pattern.

In an embodiment, the means for measuring is disposed in the Fourier plane to detect the Fourier output.

In an embodiment, the apparatus further comprises a lens for providing the Fourier output

In an embodiment, the apparatus further comprises a mirror for providing the Fourier output

There follows a description of how one or more SLMs may be used to aid the assembly of the optical system in which they are to act as an optical processing device, with reference to Figure 1, which shows an exemplary set up of a system for use with the invention.

Referring to Figure 1, an arrangement is shown with a 1-D reflective phase-modulating FLC SLM with 540 pixels. The arrangement is a 2-f system with a Fourier lens, and further comprises a silica-on-silicon waveguide array.

A 2-D SLM may be used instead of a 1-D SLM. Use of a reflective SLM is not fundamental to the invention.

Let (u,v) be the co-ordinate system at the SLM and let the incident beam be $f(u,v) \exp i\,\phi(u,v)$ where $f(u,v)$ describes the amplitude and $\phi(u,v)$ describes the phase. As an example the incident field could be an off-axis normally incident defocused Gaussian beam. For this example, the incident beam may be described by equation (1).

$$\begin{aligned} f(u,v) &= \exp-\left\{\frac{(u-u_{INC})^2+(v-v_{INC})^2}{\omega^2}\right\} \\ \exp i\phi(u,v) &= \exp-ik\left\{\frac{(u-u_{INC})^2+(v-v_{INC})^2}{2R}\right\} \end{aligned} \tag{1}$$

where u_{INC} and v_{INC} are the co-ordinates at the centre of the Gaussian beam and R is the radius of curvature.

Consider the SLM to apply a known hologram pattern $H_0(u,v)$ to the incident beam where in general H_0 will be a complex function describing phase and/or amplitude modulation. In the general case the output field from the SLM is

$H_0(u,v)\, f(u,v) \exp i\,\phi(u,v)$.

Measure the output from the SLM in the Fourier plane, using a suitably positioned lens or lenses and one or more optical receiving devices to detect the

Fourier output at one or more positions. Suitable optical receiving devices would be a photodiode, an optical fibre coupled to a photodiode or a waveguide coupled to a fibre. Let (x,y) be the co-ordinate system at the Fourier plane. The origin for x and y is the position where the lens optical axis intersects the Fourier plane. Let the Fourier transform of $H_0(u,v)\, f(u,v) \exp i\, \phi(u,v)$ be $F_0(x,y) \exp i\, \theta(x,y)$ where $F_0(x,y)$ describes the amplitude and $\theta(x,y)$ describes the phase. Hence the measured intensity is proportional to the term $F_0^2(x,y)$.

Now change the hologram pattern in a known way at the position (u_0, v_0) where it is required to characterise the beam phase and amplitude such that the hologram pattern $H(u,v)$ becomes that shown in equation (2):

$$H(u,v) = H_0(u,v) + H_1(u,v) \quad \text{at } (u,v) \text{ close to } (u_0, v_0)$$

(2)

$$H(u,v) = H_0(u,v) \qquad \text{elsewhere}$$

Hence in a known neighbourhood of the point (u_0, v_0) there is a perturbation in the hologram pattern. Therefore there is also a perturbation in the output field from the SLM, given by $H_1(u,v)\, f(u,v) \exp i\, \phi(u,v)$. The incident field amplitude and phase may be approximated to be uniform across the perturbation region, in which case the perturbation in the output field from the SLM may be represented as $H_1(u,v)\ f(u_0,v_0) \exp i\ \phi_0(u_0,v_0)$. As an example consider the perturbation to be a uniform change in phase modulation over the area of a single square pixel of side p, from an initial phase q_0 to a new phase q_1. This perturbation may be described as a "flashing pixel". For this example $H_1(u,v)$ may be represented by equation (3)

$$H_1(u,v) = \exp iq_1 - \exp iq_0 \quad \forall (u,v): |u-u_0| \le \frac{p}{2}, |v-v_0| \le \frac{p}{2}$$

$$= 0 \quad elsewhere$$

(3)

Let the Fourier transform of $H_1(u,v)$ be $g(x,y)\exp i\,\psi(x,y)$. Hence the Fourier transform of $H_1(u,v)\, f(u_0,v_0)\, \exp i\,\phi(u_0,v_0)$ is given by $f(u_0,v_0)\, \exp i\,\phi(u_0,v_0)\, g(x,y)\, \exp i\,\psi(x,y)$. So this perturbation field contains information about the phase and amplitude of the incident beam. For the example given above, the perturbation field is given by equation (4).

$$g(x,y)f(u_0,v_0) = 2\sin\left(\frac{q_1-q_0}{2}\right)p^2\frac{\sin(\pi px/f\lambda)}{\pi px/f\lambda}\frac{\sin(\pi py/f\lambda)}{\pi py/f\lambda}f(u_0,v_0)$$
$$\exp i\psi(x,y)\exp i\phi(u_0,v_0) = \exp i\left(\frac{2\pi}{f\lambda}\{u_0x+v_0y\}+\frac{\pi}{2}+q_0+\frac{q_1-q_0}{2}+\phi(u_0,v_0)\right) \quad (4)$$

where f is the focal length of the Fourier lens. From the equation the amplitude of the perturbation field in the Fourier plane is proportional to the amplitude of the incident field at the perturbation in the hologram. The phase of the perturbation field includes a constant component equal to the phase of the incident field at the perturbation in the hologram, and also a linear component in x proportional to the position of the perturbation in the hologram.

Returning to the general case, in the Fourier plane the field is the Fourier transform of the output field from the SLM. Given that a Fourier transform is a linear operation the field is the sum of the individual Fourier transforms of the original and perturbation field from the SLM. Hence the total field in the Fourier plane, $F(x,y)$ is that given by (5):

$$F(x,y) = F_0(x,y)\exp i\theta(x,y) + f(u_0,v_0)\exp i\phi(u_0,v_0)g(x,y)\exp i\psi(x,y) \quad (5)$$

The analysis given hereafter assumes the optical output to be detected by a single photodiode that is small enough such that the field amplitude and phase in the Fourier plane may be considered uniform over the active area of the

photodiode. Equations are derived for the response and data fitting methods are described to measure the amplitude variation and phase variation of the field incident on the spatial light modulator. As mentioned previously, other receiving elements could be used. Examples are an optical fibre (single mode or multimode) coupled to a photodiode. In the case of a single mode fibre a mode stripper should also be used. Other example receivers are a larger photodiode or an array of photodiodes. For each case, knowing the physics of the receiving process (which involves a coupling efficiency calculation for the optical fibre case) analytical expressions may be used to derive the receiver response, given the incident field as described in equation (5). As is demonstrated for the case of a small single photodiode, data fitting methods may be derived, based on said analytical expressions, to measure the amplitude variation and phase variation of the field incident on the spatial light modulator.

Assuming the field is detected directly by one or more photodiodes, the induced photocurrent at position *(x,y)* is proportional to the local intensity. The intensity at the Fourier plane contains 3 terms.

The expression for the intensity, *I(x,y)*, is given by equation (6).

$$\begin{aligned} I(x,y) \propto\; & F_0^{\,2}(x,y) \\ & + 2F_0(x,y)g(x,y)f(u_0,v_0)\cos\{\phi(u_0,v_0)+\psi(x,y)-\theta(x,y)\} \\ & + f^2(u_0,v_0)g^2(x,y) \end{aligned} \tag{6}$$

The first term , $F_0^2(x,y)$ is the original intensity, before the perturbation was applied.

The second term $2F_0(x,y)g(x,y,)f(u_o,v_0)\cos\{\phi(u_0,v_0)+\psi(x,y)-\theta(x,y)\}$ is a coherent coupling term between the original field in the Fourier plane, and the field component created there by the perturbation at the SLM. This second term contains information about the phase and amplitude of the beam incident on the SLM. For the example hologram perturbation the second term also contains information about the flashing pixel.

The third term $f^2(u_0,v_0)g^2(x,y)$ is the intensity that would appear at the Fourier plane if the perturbation was acting on its own, with the original field removed. This third term contains information about the amplitude of the beam incident on the SLM, but not the phase. The values that are to be extracted from the system are $f(u_0, v_0)$ and $\phi(u_0, v_0)$. The other "unknowns" are $g(x,y)$ and $\psi(x,y)-\theta(x,y)$.

For a general case where the incident beam phase varies in an unknown way. Usually what is desired is the relative amplitude variation of the beam, but not the absolute amplitude. The terms $F_0(x,y)g(x,y)$ and $g(x,y)$ are independent of the position of the perturbation at the SLM, so can be considered as a multiplying constant. The amplitude $f(u_0, v_0)$ may be measured in several ways.

A first method is to measure the intensity in a region of the Fourier plane where $F_0(x,y)$ is very weak but $g(x,y)$ is relatively stronger such that only the third term is significant. The region of the applied perturbation at the SLM is broader than the region occupied by the incident beam, hence at the Fourier transform plane the region occupied by the Fourier transform of the perturbation is narrower than the region occupied by the Fourier transform of the original field. Hence by varying the position on the SLM where the perturbation is applied a set of measurements of $(g(x,y)f(u_0,v_0))^2$ may be built up at different

positions (u_0, v_0). By taking the square root of these measurements values for the relative field amplitude at these positions may be derived.

In general there may be sidelobes or spurious diffraction orders in the beam $F_0(x,y)$ making it difficult to find such a region. Often it may be that $g(x,y)$ is relatively weak and $F_0(x,y)$ is stronger. Therefore it becomes appropriate to use the second term to measure the amplitude. In such a region the third term may be neglected and the second term estimated by subtracting the receiver output before the perturbation was applied from the receiver output in the presence of the perturbation.

A second method is to step through a sequence of distributions $H_0(x,y)$ chosen to have the same values for $F_0(x,y)$ and known changes in the values for $\theta(x,y)$. In an embodiment example $H_0(x,y)$ is a binary phase pattern, in which $F_0(x,y)$ is independent of the relative position of the pattern on the SLM, but $\theta(x,y)$ changes in a known way as the pattern position is changed on the SLM. In general let $\theta(x,y)$ be expressed as given by equation (7).

$$\theta(x,y) = \theta_0 + \theta(m) \qquad (7)$$

where m is a variable that represents the known phase associated with the pattern position, and θ_0 represents the sum of the background phase component from the hologram that is not affected by the pattern position and the phase from the incident field.

By applying a set of patterns, at different relative positions on the SLM a set of values may be built up for the term given in equation (8):

$$2F_0(x,y)g(x,y)f(u_0,v_0)\cos\{\phi(u_0,v_0)+\psi(x,y)-\theta_0(x,y)-\theta(m)\}$$

(8)

which may be further expressed as given by equation (9).

$$\alpha(x,y)f(u_0,v_0)\cos\{\beta(x,y,u_0,v_0)\}\cos(\theta(m))+\alpha(x,y)f(u_0,v_0)\sin\{\beta(x,y,u_0,v_0)\}\sin(\theta(m))$$

(9)

where $\alpha(x,y) = 2F_0(x,y)g(x,y)$ *and* $\beta(x,y,u_0,v_0) = \phi(u_0,v_0)+\psi(x,y)-\theta_0(x,y)$.

Equation (9) may be considered as a linear equation in $\cos(\theta(m))$ and $\sin(\theta(m))$, with unknown coefficients $c = \alpha(x,y)\cos\beta(x,y,u_0,v_0)\,f(u_0,v_0)$ and $d = \alpha(x,y)\sin\beta(x,y,u_0,v_0)\,f(u_0,v_0)$. Any suitable data fitting method may be used to extract values for these coefficients c and d. A relative value for the amplitude may then be calculated from equation (10) (remembering that $\alpha(x,y)$ acts like a multiplying constant at any Fourier output position (x,y)).

$$\alpha(x,y)f(u_0,v_0)=\sqrt{c^2+d^2}$$

(10)

Other methods could also be used to process the data.

While the above example assumes an invariant $F_0(x,y)$ and known changes in $\theta(x,y)$ hologram patterns could be selected that maintain an invariant $\theta(x,y)$ and change $F_0(x,y)$ in a known way, or that change both in a known way. Another method is to change the amplitude and/or the phase of the perturbation hologram in a known way. The general principle is to be able to take a sequence of measurements with some known parameters changing in a known way and use data fitting to extract the values of the unknown parameters. These unknown parameters may be combined in a way that extracts the incident field amplitude without requiring knowledge of the incident field phase.

Another measurement that may be required is to check that the pixels are functioning correctly. Take a measurement of the output intensity with the original hologram applied; this could be the coupling efficiency into a fibre, or the output from a photodiode, or the outputs from a photodiode array. Now flash a pixel, one at a time, preferably with a phase perturbation $q_1 - q_0$ close to π so as to maximise the effect. Calculate the relative amplitude as described above. If there is no significant amplitude then either the pixel is outside the area of the incident beam or the pixel drive circuit is not functioning. If the amplitude varies in a smooth manner like the expected profile then the pixels are working correctly. If there is a discontinuous jump in the response to a higher value then the pixel may be shorted to another pixel. If there is a discontinuous jump to a lower value then the pixel is not being driven correctly.

In some systems what is required is to check or measure the position of the field with respect to the SLM pixels. The peak measured amplitude will occur when the pixel being flashed coincides with the peak of the incident beam.

In many cases it may also be required to measure the phase variation in the incident field. The methods described hereafter explain how to measure the variation in the u direction in the interests of clarity. However the method is easily extended to measurements in both u and v directions.

Given the data fitted values of the coefficients c and d the phase term $\beta(x,y,u_0,v_0)$ may be calculated using equation (11).

$$\cos(\beta(x,y,u_0,v_0)) = \frac{c}{\alpha(x,y)f(u_0,v_0)}$$
$$\sin(\beta(x,y,u_0,v_0)) = \frac{d}{\alpha(x,y)f(u_0,v_0)}$$

(11)

Let the initial position (u_0, v_0) be a reference point such that the phase at any arbitrary point (u,v) is measured with respect to the phase at (u_0, v_0). Using (4) there is obtained a general expression for $\beta(x,y,u_0,v_0)$ as shown in equation (12):

$$\beta(x,y,u_0,v_0)=\frac{2\pi u_0 x}{f\lambda}+\phi(u_0,v_0)+\left\{\frac{2\pi v_0 x}{f\lambda}+\frac{\pi}{2}+\frac{q_0+q_1}{2}-\theta_0(x,y)\right\} \qquad (12)$$

Now consider the effect of changing the position of the hologram perturbation to (u,v_0) but maintaining the position of the output receiver at (x,y). The value of β becomes that shown in equation (13).

$$\beta(x,y,u,v_0)=\frac{2\pi ux}{f\lambda}+\phi(u,v_0)+\left\{\frac{2\pi v_0 x}{f\lambda}+\frac{\pi}{2}+\frac{q_0+q_1}{2}-\theta_0(x,y)\right\} \qquad (13)$$

The difference in the values of β contains two terms, the first (in curly brackets) is the required phase difference being measured, while the second is a linear phase term, as shown in equation (14).

$$\beta(x,y,u,v_0)-\beta(x,y,u_0,v_0)=\{\phi(u,v_0)-\phi(u_0,v_0)\}+\frac{2\pi(u-u_0)x}{f\lambda} \qquad (14)$$

Therefore to extract the required phase difference a method is needed to estimate or measure the linear phase term. Given knowledge of the pixel pitch on the SLM it is straightforward to calculate $(u-u_0)$. Similarly knowledge of the wavelength, λ, is established. The focal length can be measured. Therefore it is possible to know to a high degree of accuracy the value of $2\pi(u-u_0)/f\lambda$. What may be difficult is to obtain an accurate value of x, the distance in the x direction from the point where the lens optical axis intersects the Fourier plane to the receiving element.

One method to overcome this difficulty is to pre-calibrate the system with a reference beam. This could be a well-collimated beam, or a beam of known phase variation (using for example a pinhole to generate the reference beam), or a beam such that the phase of any arbitrary beam needs to be measured with respect to the reference beam. Let the subscript R represent the corresponding measurements for the reference beam. Hence equation (15) is obtained:

$$\beta_R(x,y,u,v_0)-\beta_R(x,y,u_0,v_0)=\{\phi_R(u,v_0)-\phi_R(u_0,v_0)\}+\frac{2\pi(u-u_0)x}{f\lambda}$$

(15)

Therefore if the β difference is measured for the reference beam and the phase variation across the reference beam is known, the value of the linear phase term may be calculated. Furthermore, by repeating this process for several different positions u on the SLM a data fitting method may be used to calculate the value of the unknown parameter x.

Without knowledge of the phase variation of the reference beam but with a need to use it as a baseline, it is necessary to measure the β difference for the beam under test, and subtract from it the β difference for the reference beam, at the same positions u and u_0. Alternatively interpolation may be used to predict the β difference for the reference beam if it has not been measured at precisely the required points. An expression may be obtained for the phase variation with respect to the baseline variation, as shown in equation (16):

$$\begin{aligned}&\beta(x,y,u,v_0)-\beta(x,y,u_0,v_0)-\{\beta_R(x,y,u,v_0)-\beta_R(x,y,u_0,v_0)\}\\&=\phi(u,v_0)-\phi(u_0,v_0)-\{\phi_R(u,v_0)-\phi_R(u_0,v_0)\}\end{aligned}$$

(16)

It is possible to perform the invention with embodiments using either multiphase or binary phase SLMs. Multiphase pixellated SLMs may incorporate an integral or non-integral quarter-wave plate or a wave plate

having a similar effect to provide polarisation insensitivity where a liquid crystal having out of plane tilt is used.

The above description refers to LCOS SLMs. However the invention is not so limited but instead extends to the full scope of the appended claims.

Claims

1. A method of measuring amplitude and phase variations in a beam of light comprising causing the beam to be incident upon a spatial array displaying a pixellated first phase distribution, in a measuring region of said spatial array causing the phase distribution to assume a new value while retaining the first phase distribution outside the measuring region, in the Fourier plane determining the change in intensity resulting from the change in phase distribution

2. A method of characterising a beam of light, comprising

disposing a LCOS SLM in the path of the beam;

causing the LCOS SLM to display a first hologram pattern;

at a location in said beam where the amplitude and phase of the beam are to be characterised, changing the hologram pattern to a second hologram pattern; and

measuring the effect of said change by measuring an intensity.

3. A method as claimed in claim 2, wherein. the output from the SLM is measured in the Fourier plane to detect the Fourier output.

4. A method as claimed in any preceding claim, comprising measuring the intensity in a region of the Fourier plane where the amplitude distribution associated with the beam modulated by the original hologram is relatively stronger, but the amplitude distribution at the Fourier plane of the field component created by the perturbation in the hologram is relatively stronger, varying the position on the SLM where the perturbation is applied.

5. A method as claimed in claim 4 further comprising taking the square root of a set of values obtained.

6. A method as claimed in any preceding claim, comprising stepping through a sequence of phase distributions.

7. A method as claimed in any preceding claim, comprising varying the phase shift in a respective single pixel.

8. A method as claimed in claim 3 comprising manipulating hologram patterns to obtain information related to a coherent coupling term to thereby derive amplitude information.

9. A method as claimed in claim 3 comprising manipulating hologram patterns to obtain information related to a coherent coupling term to thereby derive phase information.

10. Apparatus for measuring amplitude and phase variations in a beam of light, the apparatus comprising a pixellated spatial array, each pixel being controllable to apply any of plural phase shifts to input light, whereby the array displays a desired distribution of phase modulation,

means for causing the array to display a first selected distribution of phase modulation; means for changing the first distribution in a measuring region of said spatial array to assume a new distribution while retaining the first phase distribution outside the measuring region,

means disposed in the Fourier plane for determining a change in intensity of light resulting from the change in phase distribution

11. Apparatus as claimed in claim 10, wherein the spatial array has only two possible values of phase shift per pixel.

12. Apparatus as claimed in claim 10, wherein the spatial array has more than two possible values of phase shift per pixel.

13. Apparatus for characterising a beam of light, comprising

a LCOS SLM arranged so that a said beam of light can be incident upon it;

means for causing the LCOS SLM to display a first hologram pattern; means for changing the hologram pattern to a second hologram pattern at a location in said beam where the amplitude and phase of the beam are to be characterised; and

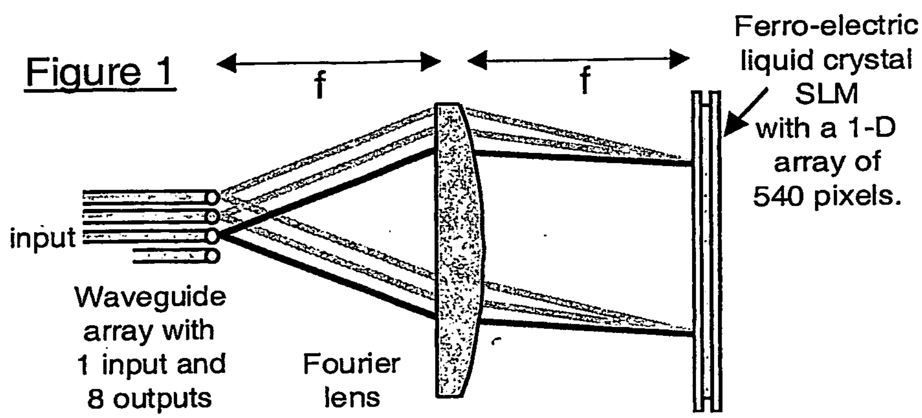
means for measuring an intensity of light to determine the effect of said change of hologram pattern.

14. Apparatus as claimed in claim 13, wherein the means for measuring is disposed in the Fourier plane to detect the Fourier output.

15. Apparatus as claimed in claim 13 or 14, further comprising a lens for providing the Fourier output

16. Apparatus as claimed in claim 13, 14 or 15, further comprising a mirror for providing the Fourier output

Figure 1


f
f
Ferro-electric
liquid crystal
SLM
with a 1-D
array of
540 pixels.
input
Waveguide
array with
1 input and
8 outputs
Fourier
lens

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